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(54) Title: NOVEL ION EXCHANGE POROUS RESINS FOR SOLID PHASE EXTRACTION AND CHROMATOGRAPHY

(57) Abstract

Embodiments of the present invention are directed to porous resins for solid phase extractions. The resins feature at least one hydrophobic component, at least one hydrophilic component and at least one ion exchange functional group. The resins exhibit superior wetting and ion exchange performance.

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NOVEL ION EXCHANGE POROUS RESINS FOR SOLID PHASE EXTRACTION AND CHROMATOGRAPHY

Field of the Invention

This invention relates generally to novel porous resins for solid phase extraction and chromatography which contain at least one hydrophobic component, at least one hydrophilic component and at least one ion exchange functional group.

Background of the Invention

Solid phase extraction (SPE) is a chromatographic technique which is widely used, e.g., for preconcentration and cleanup of analytical samples, for purification of various chemicals, and for removal of toxic or valuable substances from aqueous solutions. SPE is usually performed using a column or cartridge containing an appropriate resin. SPE procedures have been developed using sorbents which can interact with analytes by hydrophobic, ion exchange, chelation, sorption, and other mechanisms, to bind and remove the analytes from fluids. Since different SPE applications can require different sorbents, there is a need for sorbents with novel properties which have unique selectivities.

Summary of the Invention

It is an object of the invention to provide compounds which can be used as porous resins for solid phase extraction and chromatography which exhibit superior wetting characteristics.

It is yet another object of the invention to provide porous resin compounds which have unique selectivities.

porous resin compounds which can selectively capture analytes of interest and allow interfering analytes to pass through unretained.

It is yet another object of the invention to provide porous resin compounds having an ion exchange functional group, a hydrophobic component and a hydrophilic polar component.

It is yet another object of the invention to utilize the novel porous resins of this invention to isolate or remove a solute from a solution.

Still another object of the invention is to utilize the novel porous resins of this invention to analytically determine the level of a solute in a solution.

In one aspect, the invention features a compound of the formula:

$$-(A)_n-(B)_m-(C)_p- \qquad \text{(I)}$$

and salts thereof,

wherein the order of A, B and C may be random, block, or a combination of random and block;

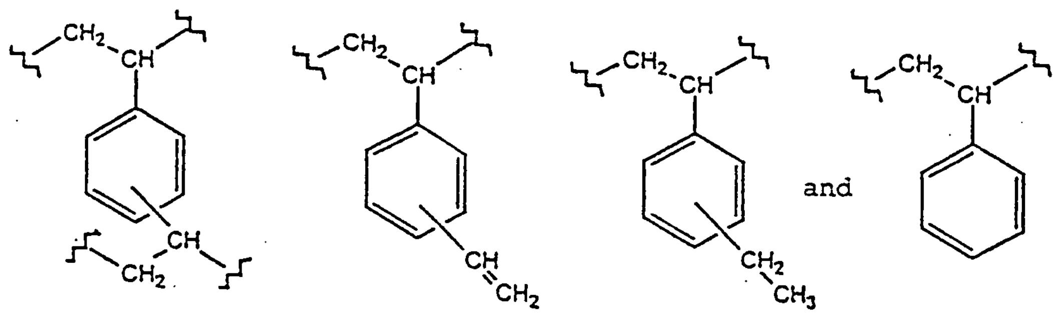
wherein

$$\frac{1}{100} < \frac{(p+n)}{m} < \frac{100}{1}$$

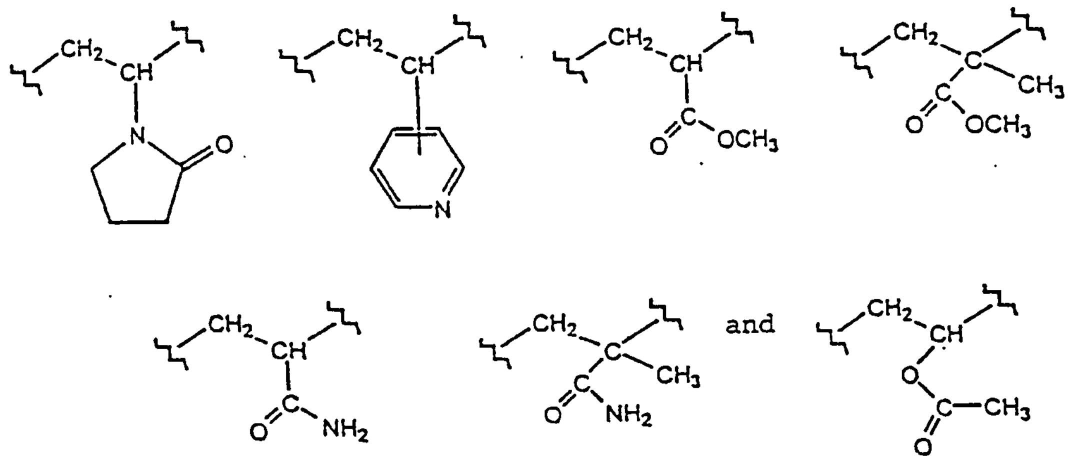
and

$$\frac{1}{500} < \frac{p}{n} < \frac{100}{1}$$

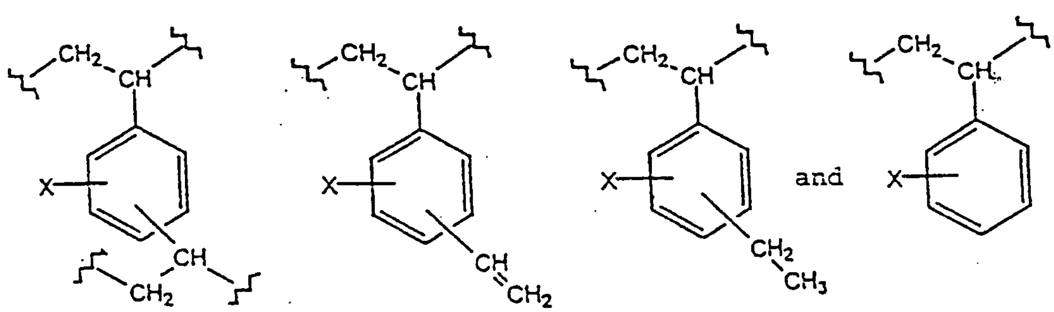
wherein A is selected from the group consisting of



wherein B is selected from the group consisting of



wherein C is A or modified A, wherein modified A is selected from the group consisting of



wherein X is selected from the group consisting of SO_3H, CH_2CO_2H, $CH_2CH(CO_2H)_2$, CO_2H, PO_3H_2, PO_2H_2, $CH_2PO_3H_2$, CH_2Cl, CH_2NH_2, $CH_2N[(CH_2)_yCH_3]_2$ wherein y is any integer from

0 to 18, $CH_2N^+[(CH_2)_{y=}CH_3]_3D^-$ wherein y= is any integer from 0 to 18 and D^- is an anion, SO_2NHR wherein R is polyethylenimine, and CH_2NHR wherein R is polyethylenimine.

Another aspect of the invention is a porous resin formed by copolymerizing at least one hydrophobic monomer and at least one hydrophilic monomer so as to form a copolymer, and subjecting the copolymer to a sulfonation reaction so as to form a sulfonated copolymer comprising at least one ion-exchange functional group, at least one hydrophilic component and at least one hydrophobic component.

In preferred embodiments, the hydrophobic monomer is divinylbenzene, the hydrophilic monomer is N-vinylpyrrolidone, and the copolymer is a poly(divinylbenzene-co-N-vinylpyrrolidone). Preferably, the porous resin is a sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone).

Another aspect of the invention is a porous resin for solid phase extraction or chromatography comprising at least one ion-exchange functional group, at least one hydrophilic component and at least one hydrophobic component.

Another aspect of the invention is a method for treating a solution to isolate or remove a solute. A solution having a solute is contacted with a porous resin under conditions so as to allow sorption of the solute to the porous resin. The porous resin comprises at least one ion-exchange functional group, at least one hydrophilic polar component and at least one hydrophobic component. In certain embodiments, the solute is removed from the porous resin. In certain embodiments, the ion-exchange

functional group is SO_3H, CH_2CO_2H, $CH_2CH(CO_2H)_2$, CO_2H, PO_3H_2, PO_2H_2, $CH_2PO_3H_2$, CH_2Cl, CH_2NH_2, $CH_2N[(CH_2)_yCH_3]_2$ wherein y is any integer from 0 to 18, $CH_2N^+[(CH_2)_{y=}CH_3]_3D^-$ wherein y= is any integer from 0 to 18 and D^- is an anion, SO_2NHR wherein R is polyethylenimine, or CH_2NHR wherein R is polyethylenimine. In certain embodiments, the hydrophilic monomer comprises a heterocyclic group, e.g., a saturated, unsaturated or aromatic heterocyclic group. Examples include nitrogen-containing heterocyclic groups, e.g., a pyridyl group, e.g., 2-vinylpyridine, 3-vinylpyridine or 4-vinylpyridine, or a pyrrolidonyl group, e.g., N-vinylpyrrolidone. In certain embodiments, the hydrophobic monomer comprises an aromatic carbocyclic group, e.g., a phenyl group or a phenylene group, or a straight chain C_2-C_{18}-alkyl group or a branched chain C_2-C_{18}-alkyl group. The hydrophobic monomer can be, e.g., styrene or divinylbenzene. A preferred copolymer is a poly(divinylbenzene-co-N-vinylpyrrolidone). A preferred porous resin is a compound of formula I and salts thereof. Preferably, the porous resin is a sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone).

Another aspect of the invention is a method for analytically determining the level of solute in a solution. A solution having a solute is contacted with a porous resin under conditions so as to allow sorption of the solute to the porous resin. The resin comprises at least one ion-exchange functional group, at least one hydrophilic polar component and at least one hydrophobic component. The porous resin having the sorbed solute is washed with a solvent under conditions so as to desorb the

solute from the porous resin. The level of the desorbed solute present in the solvent after the washing is analytically determined. In certain embodiments, the porous resin is a compound of formula I and salts thereof. Preferably, the porous resin is a sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone).

Another aspect of the invention is a solid phase extraction cartridge comprising a porous resin packed inside an open-ended container. The porous resin comprises at least one ion-exchange functional group, at least one hydrophilic polar component and at least one hydrophobic component. In certain embodiments, the porous resin is a compound of formula I and salts thereof. Preferably, the porous resin is a sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone).

The above and other features, objects and advantages of the present invention will be better understood by a reading of the following specification in conjunction with the drawings.

Brief Description of the Drawings

Fig. 1 depicts the formulas of the model compounds acetaminophen, p-toluamide, caffeine, procainamide, ranitidine, amphetamine, methamphetamine and m-toluidine.

Fig. 2A is a graph depicting the effect of ionic strength on chromatographic retention for poly(divinylbenzene-co-N-vinylpyrrolidone), Batch 6B.

Fig. 2B is a graph depicting the effect of ionic strength on chromatographic retention for sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone), Batch JJL03-100.

Fig. 3 is a graph depicting the effect of sulfonation

on chromatographic retention of model compounds for certain sulfonated resins of this invention.

Fig. 4 is a chromatogram depicting separation of model compounds using a SymmetryShield™ RP_8 column.

Figs. 5A and 5B are chromatograms of methanol/ammonium hydroxide extract from porcine plasma using sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone), Batch JJL03-124 and Batch JJL03-100, for solid phase extraction, where ranitidine is an internal standard.

Detailed Description

This invention provides for a compound of the formula:

$$-\!(A)_n\!-\!(B)_m\!-\!(C)_p\!- \qquad (I)$$

and salts thereof,

wherein the order of A, B and C may be random, block, or a combination of random and block;

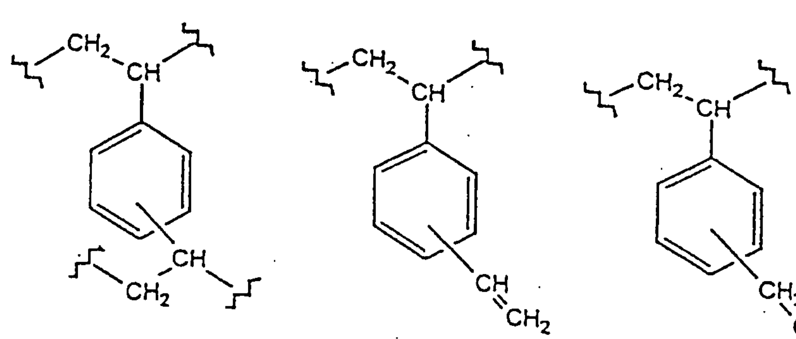
wherein

$$\frac{1}{100} < \frac{(p+n)}{m} < \frac{100}{1}$$

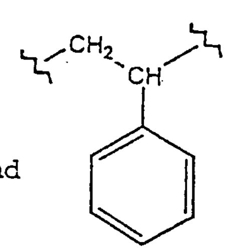
and

$$\frac{1}{500} < \frac{p}{n} < \frac{100}{1}$$

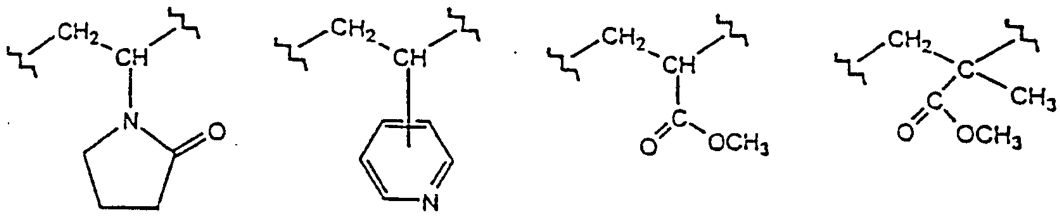
wherein A is selected from the group consisting of

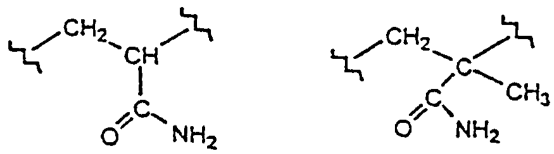
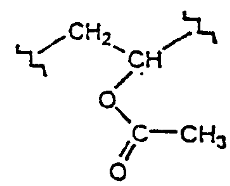


and

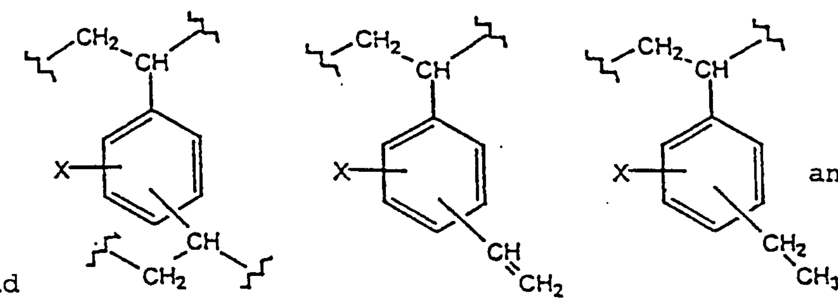
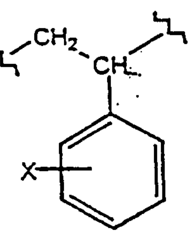


wherein B is selected from the group consisting of



 and 

wherein C is A or modified A, wherein modified A is selected from the group consisting of

 and 

and

wherein X is selected from the group consisting of SO_3H, CH_2CO_2H, $CH_2CH(CO_2H)_2$, CO_2H, PO_3H_2, PO_2H_2, $CH_2PO_3H_2$, CH_2Cl, CH_2NH_2, $CH_2N[(CH_2)_yCH_3]_2$ wherein y is any integer rom 0 to 18, $CH_2N^+[(CH_2)_{y=}CH_3]_3D^-$ wherein y= is any integer from 0 to 18 and D^- is an anion, SO_2NHR wherein R is polyethylenimine, and CH_2NHR wherein R is polyethylenimine.

Preferred compounds are where X is SO_3H, $CH_2PO_3H_2$, CH_2CO_2H, or combinations thereof. The most preferred compound is where X is SO_3H.

Preferably, X is present at a concentration of about 0.01 to about 5.0, more preferably at a concentration of about 0.6 to about 3.2, more preferably yet at a

concentration of about 0.8 to about 2.1, and most preferably at a concentration of about 1.0, milliequivalents per gram of compound.

By block ordering is meant ordering in which individual units are joined in a pattern or repeated sequence. By random ordering is meant ordering in which individual units are joined randomly.

The compounds of this invention can be prepared, e.g., by functionalizing, i.e., chemically altering, a copolymer having at least one hydrophobic monomer, e.g., divinylbenzene, styrene, or ethylvinylbenzene, and at least one hydrophilic monomer, e.g., N-vinylpyrrolidone, N-vinylpyridine, methacrylate, methyl methacrylate, vinyl acetate, acrylamide or methacrylamide. Preferably, the hydrophobic monomer is divinylbenzene. Preferably, the hydrophilic monomer is N-vinylpyrrolidone. The copolymer can be prepared via standard synthetic methods known to those skilled in the art, e.g., as described in Example 1. Such a copolymer, e.g., poly(divinylbenzene-co-N-vinylpyrrolidone), can be functionalized by the addition of an ion-exchange functional group, an X group, which can be cationic, e.g., SO_3H, CH_2CO_2H, $CH_2CH(CO_2H)_2$, CO_2H, PO_3H_2, PO_2H_2 or $CH_2PO_3H_2$, or anionic, e.g., CH_2NH_2, $CH_2N[(CH_2)_yCH_3]_2$, $CH_2N^+[(CH_2)_{y=}CH_3]_3D^-$, SO_2NHR or CH_2NHR, or intermediate, e.g., CH_2Cl. Such additions can be accomplished, e.g., as decribed in Lieto et al., Chemtech, pgs. 46-53 (1983); Mitchell et al., Tetrahedron Letters, pgs. 3795-3798 (1976); and K. Unger, "Packings and Stationary Phases in Chromatographic Techniques," in Chromatographic Science Series, Vol. 47, pgs. 585-720 (1990). See, e.g., Example 2, which describes the sulfonation of poly(divinylbenzene-co-N-vinylpyrrolidone).

The novel compounds of this invention can be used, e.g., as porous resins for solid phase extraction and chromatography. By solid phase extraction is meant a process employing a solid phase for isolating classes of molecular species from fluid phases such as gases and liquids by, e.g., sorption, ion exchange, chelation, size exclusion (molecular filtration), affinity or ion pairing mechanisms.

The invention also includes a porous resin formed by copolymerizing at least one hydrophobic monomer and at least one hydrophilic monomer so as to form a copolymer, and subjecting the copolymer to a sulfonation reaction so as to form a sulfonated copolymer comprising at least one ion-exchange functional group, at least one hydrophilic component and at least one hydrophobic component.

By porous resin is meant a member of a class of crosslinked polymer particles penetrated by channels through which solutions can diffuse. Pores are regions between densely packed polymer chains. By monomer is meant a molecule comprising one or more polymerizable functional groups prior to polymerization, or a repeating unit of a polymer. By copolymer is meant a polymer comprising two or more different monomers. By ion-exchange functional group is meant a group where the counter-ion is partially free and can readily be exchanged for other ions of the same sign. By hydrophilic is meant having an affinity for, attracting, adsorbing or absorbing water. By hydrophobic is meant lacking an affinity for, repelling, or failing to adsorb or absorb water.

In a preferred embodiment, the hydrophobic monomer is divinylbenzene. In a preferred embodiment, the hydrophilic monomer is N-vinylpyrrolidone. In a preferred embodiment, the copolymer is a poly(divinylbenzene-co-N-

vinylpyrrolidone). In a preferred embodiment, the porous resin is a sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone). Preferably, the sulfonate groups are present at a concentration of about 0.01 to about 5.0, more preferably at a concentration of about 0.6 to about 3.2, more preferably yet at a concentration of about 0.8 to about 2.1, and most preferably at a concentration of about 1.0, milliequivalents per gram of porous resin.

The invention also includes a porous resin for solid phase extraction or chromatography comprising at least one ion-exchange functional group, at least one hydrophilic component and at least one hydrophobic component.

The ion exchange functional groups enable the porous resin to interact with basic and cationic solutes. The hydrophilic polar components enable the porous resin to have polar interactions and hydrogen bonding capabilities with solutes. The hydrophobic components enable the porous resin to have affinity towards nonpolar solutes through hydrophobic interaction. Since the porous resins of this invention have a combination of various interaction forces towards solutes, they are very useful resins for, e.g., solid phase extraction, ion exchange, liquid chromatography applications. For example, these novel porous resins can be used to bind, recover and/or remove solutes from fluids.

The invention also includes a method for treating a solution to isolate or remove a solute. A solution having a solute is contacted with a porous resin under conditions so as to allow sorption of the solute to the porous resin. The porous resin comprises at least one ion-exchange functional group, at least one hydrophilic polar component and at least one hydrophobic component. In certain embodiments, the solute is removed from the porous resin.

By sorption is meant capable of taking up and holding by absorption or adsorption.

In certain embodiments, the ion-exchange functional group is SO_3H, CH_2CO_2H, $CH_2CH(CO_2H)_2$, CO_2H, PO_3H_2, PO_2H_2, $CH_2PO_3H_2$, CH_2Cl, CH_2NH_2, $CH_2N[(CH_2)_yCH_3]_2$ wherein y is any integer from 0 to 18, $CH_2N^+[(CH_2)_{y=}CH_3]_3D^-$ wherein y= is any integer from 0 to 18 and D^- is an anion, SO_2NHR wherein R is polyethylenimine, or CH_2NHR wherein R is polyethylenimine. Preferably, the ion-exchange functional group is SO_3H. Preferably, the ion-exchange functional groups are present at a concentration of about 0.01 to about 5.0, more preferably at a concentration of about 0.6 to about 3.2, more preferably yet at a concentration of about 0.8 to about 2.1, and most preferably at a concentration of about 1.0, milliequivalents per gram of porous resin.

In certain embodiments, the hydrophilic polar component is an amide group, ester group, carbonate group, carbamate group, urea group, hydroxy group or pyridyl group.

In certain embodiments, the porous resin comprises a copolymer having at least one ion-exchange functional group, and the copolymer comprises at least one hydrophilic monomer and at least one hydrophobic monomer. Preferably, the hydrophilic monomer comprises a heterocyclic group, e.g., a saturated, unsaturated or aromatic heterocyclic group. Examples include nitrogen-containing heterocyclic groups, e.g., a pyridyl group, e.g., 2-vinylpyridine, 3-vinylpyridine or 4-vinylpyridine, or a pyrrolidonyl group, e.g., N-vinylpyrrolidone. Preferably, the hydrophobic monomer comprises an aromatic carbocyclic group, e.g., a phenyl group or a phenylene

group, or a straight chain C_2-C_{18}-alkyl group or a branched chain C_2-C_{18}-alkyl group. The hydrophobic monomer can be, e.g., styrene or divinylbenzene. A preferred copolymer is a poly(divinylbenzene-co-N-vinylpyrrolidone).

A preferred porous resin is a compound of formula I and salts thereof described supra. Preferably, the porous resin is a sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone).

In preferred embodiments, the porous resin comprises at least about 12 mole percent N-vinylpyrrolidone. In preferred embodiments, the porous resin comprises less than about 30 mole percent N-vinylpyrrolidone. By mole percent is meant the mole fraction, expressed as a percent, of the monomer of interest relative to the total moles of the various (two or more) monomers which compose the copolymer of the porous resin. Preferably, the porous resin has solid phase extraction capability.

The porous resin can be in the form of, e.g., beads, pellets, or any other form desirable for use. The porous resin particles can have, e.g., a spherical shape, a regular shape or an irregular shape. Preferably, the particles are beads having a diameter in the range from about 3 to about 500 µm, preferably from about 20 to about 200 µm. Preferably, the porous resin has a specific surface area in the range from about 50 to about 850 square meters per gram and pores having a diameter ranging from about 0.5 nm to about 100 nm. In certain embodiments, the porous resin is incorporated in a matrix.

In certain embodiments, more than one type of functionalized porous resin can be used in the columns, cartridges, and the like of the present invention.

The solute can be, e.g., any molecule having a hydrophobic, hydrophilic, or ionic interaction or a

combination of two or three of these interactions. Preferably, the solute is an organic compound of polarity suitable for adsorption onto the porous resin. Such solutes include,.e.g., drugs, pesticides, herbicides, toxins and environmental pollutants, e.g., resulting from the combustion of fossil fuels or other industrial activity, such as metal-organic compounds comprising a heavy metal such mercury, lead or cadmium. The solutes can also be metabolites or degradation products of the foregoing materials. Solutes also include, e.g., biomolecules, such as proteins, peptides, hormones, polynucleotides, vitamins, cofactors, metabolites, lipids and carbohydrates.

The solution e.g., can comprise water, an aqueous solution, or a mixture of water or an aqueous solution and a water-miscible polar organic solvent, e.g., methanol, ethanol, N,N-dimethylformamide, dimethylsulfoxide or acetonitrile. In a preferred embodiment, the solution is an acidic, basic or neutral aqueous, i.e., between about 1% and about 99% water by volume, solution. The solution comprising the solute can, optionally, further contain one or more additional solutes. In one embodiment, the solution is an aqueous solution which includes a complex variety of solutes. Solutions of this type include, e.g., blood, plasma, urine, cerebrospinal fluid, synovial fluid and other biological fluids, including, e.g., extracts of tissues, such as liver tissue, muscle tissue, brain tissue or heart tissue. Such extracts can be, e.g., aqueous extracts or organic extracts which have been dried and subsequently reconstituted in water or in a water/organic mixture. Solutions also include, e.g., ground water, surface water, drinking water or an aqueous or organic extract of an environmental sample, such as a soil sample.

Other examples of solutions include a food substance, such as a fruit or vegetable juice or milk or an aqueous or aqueous/organic extract of a food substance, such as fruit, vegetable, cereal or meat. Other solutions include, e.g., natural products extractions from plants and broths.

The solution can be contacted with the porous resin in any fashion which allows sorption of the solute to the porous resin, such as a batch or chromatographic process. For example, the solution can be forced through a porous polymer column, disk or plug, or the solution can be stirred with the porous resin, such as in a batch-stirred reactor. The solution can also be added to a porous resin-containing well of a microtiter plate. The porous resin can take the form of, e.g., beads or pellets. The solution is contacted with the porous resin for a time period sufficient for the solute of interest to substantially sorb onto the porous resin. This period is typically the time necessary for the solute to equilibrate between the porous resin surface and the solution. The sorption or partition of the solute onto the porous resin can be partial or complete.

In one embodiment, the porous resin is packed as particles within an open-ended container to form a solid phase extraction cartridge.

The invention also includes a method for analytically determining the level of solute in a solution. A solution having a solute is contacted with a porous resin under conditions so as to allow sorption of the solute to the porous resin. The resin comprises at least one ion-exchange functional group, at least one hydrophilic polar component and at least one hydrophobic component. The porous resin having the sorbed solute is washed with a

solvent under conditions so as to desorb the solute from the porous resin. The level of the desorbed solute present in the solvent after the washing is analytically determined.

In certain embodiments, the porous resin is a compound of formula I and salts thereof. Preferably, the porous resin is a sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone).

The solution contacted with the porous resin can comprise the solute of interest in dilute form, e.g., at a concentration too low for accurate quantitation. By sorbing the solute onto the porous resin and then, e.g., desorbing the solute with a substantially smaller volume of a less polar solvent, a solution which includes the solute of interest can be prepared having a substantially higher concentration of the solute of interest than that of the original solution. The method can also result in solvent exchange, that is, the solute is removed from a first solvent and re-dissolved in a second solvent.

Solvents which are suitable for desorbing the solute from the porous resin can be, e.g., polar water-miscible organic solvents, such as alcohols, e.g., methanol, ethanol or isopropanol, acetonitrile, acetone, and tetrahydrofuran, or mixtures of water and these solvents. The desorbing solvent can also be, e.g., a nonpolar or moderately polar water-immiscible solvent such as dichloromethane, diethylether, chloroform, or ethylacetate. Mixtures of these solvents are also suitable. Preferred solvents or solvent mixtures must be determined for each individual case. A suitable solvent can be determined by one of ordinary skill in the art without undue experimentation, as is routinely done in chromatographic methods development (see, e.g., McDonald

and Bouvier, eds., Solid Phase Extraction Applications Guide and Bibliography, "A Resource for Sample Preparation Methods Development," 6th edition, Waters, Milford, MA (1995); Snyder and Kirkland, Introduction to Modern Liquid Chromatography, New York: J. Wiley and Sons (1974)).

The level of the desorbed solvent present in the solvent can be analytically determined by a variety of techniques known to those skilled in the art, e.g., high performance liquid chromatography, gas chromatography, gas chromatrography/mass spectrometry, or immunoassay.

The invention also includes a solid phase extraction cartridge comprising a porous resin packed inside an open-ended container. The porous resin comprises at least one ion-exchange functional group, at least one hydrophilic polar component and at least one hydrophobic component. In certain embodiments, the porous resin is a compound of formula I and salts thereof discussed supra. Preferably, the porous resin is a sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone).

The container can be, e.g., a cylindrical container or column which is open at both ends so that the solution can enter the container through one end, contact the porous resin within the container, and exit the container through the other end. The porous resin can be packed within the container as small particles, such as beads having a diameter between about 3 μm and about 500 μm, preferably between about 20 μm and about 200 μm. In certain embodiments, the porous resin particles can be packed in the container enmeshed in a porous membrane.

The container can be formed of any material which is compatible, within the time frame of the solid phase extraction process, with the solutions and solvents to be used in the procedure. Such materials include glass and

various plastics, such as high density polyethylene and polypropylene. In one embodiment, the container is cylindrical through most of its length and has a narrow tip at one end. One example of such a container is a syringe barrel. The amount of porous resin within the container is limited by the container volume and can range from about 0.001 g to about 50 kg, and preferably is between about 0.025 g and about 1 g. The amount of porous resin suitable for a given extraction depends upon the amount of solute to be sorbed, the available surface area of the porous resin and the strength of the interaction between the solute and the porous resin. This amount can be readily determined by one of ordinary skill in the art. The cartridge can be a single use cartridge, which is used for the treatment of a single sample and then discarded, or it can be used to treat multiple samples.

The following non-limiting examples further illustrate the present invention.

EXAMPLES

Example 1: Preparation of Poly(divinylbenzene-co-N-vinylpyrrolidone) Copolymers

This example illustrates the preparation of poly(divinylbenzene-co-N-vinylpyrrolidone) copolymers.

To a 3000 mL flask was added a solution of 5.0 g hydroxypropylmethylcellulose (Methocel E15, Dow Chemical Co., Midland, MI) in 1000 mL water. To this was added a solution of 175 g divinylbenzene (DVB HP-80, Dow), 102 g N-vinyl-2-pyrrolidone (International Specialty Products, Wayne, NJ), and 1.85 g azobisisobutyronitrile (Vazo 64, Dupont Chemical Co., Wilmington, DE) in 242 g toluene.

The 80% purity divinylbenzene above may be substituted with other hydrophobic monomers such as styrene or

ethylvinylbenzene, or lower purity grades of divinylbenzene, but 80% purity divinyl-benzene is preferred. The N-vinylpyrrolidone above may be substituted with other hydrophilic monomers such as N-vinyl-pyridine, methacrylate, methyl methacrylate, vinyl acetate, acrylamide, or methacrylamide, but N-vinylpyrrolidone is preferred.

The resulting biphasic mixture was stirred for 30 minutes at room temperature using sufficient agitation to form oil droplets of the desired micron size. The resulting suspension was then heated under moderate agitation to 70°C and maintained at this temperature for 20 hours. The suspension was cooled to room temperature, filtered and washed with methanol. The filter cake was then dried in vacuo for 16 hours at 80°C. The composition of the product polymer was determined by elemental analysis. Elemental analysis: N: 2.24%; mole percent N-vinylpyrrolidone: 20%.

A series of poly(divinylbenzene-co-N-vinylpyrrolidone) copolymers comprising about 13, 14, 16, and 22 mole percent N-vinylpyrrolidone was also prepared by this method by varying the starting ratio of the divinylbenzene and N-vinylpyrrolidone monomers.

Example 2: Sulfonation of Poly(divinylbenzene-co-N-vinylpyrrolidone) Copolymers

This example illustrates the preparation of sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone) porous resins. Copolymers obtained from Example 1, preferably poly(divinylbenzene-co-N-vinylpyrrolidone), can be derivatized with sulfuric acid (95-98%, A.C.S. reagent, Aldrich, 25,810-5, Milwaukee, WI). Most preferably, OASIS® HLB (obtained from Waters Corp., Milford, MA) is used.

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with different ion exchange capacities and which can serve as a guideline for process design and quality control.

Equation 1: Ion exchange capacity of copolymer (meq HSO_3/g sulfonated copolymer) = 0.53 + 0.018 x [Temperature] + 0.00029 x [Time],

wherein

[Temperature] = the reaction temperature in degree celsius.

[Time] = the reaction time in minutes.

Table 1 - Sulfonated Poly(divinylbenzene-co-N-vinylpyrrolidone) Porous Resins and Respective Reaction Conditions

Batch No.	Temperature (°C)	Reaction Time (min)	H_2SO_4 (gram)	OASIS®-HLB (gram)	Sulfonate groups (HSO_3) (meq/g)
JJL03-99	25	1470	250	12	1.34
JJL03-100	100	360	377	15	2.52
JJL03-114	24	70	200	20	1.00
JJL03-115	122	1380	600	20	3.19
JJL03-119	21	15	200	20	0.904
JJL03-123	122	1380	800	20	3.17
JJL03-124	22	15	160	20	0.898
JJL03-128	22	75	160	20	1.01
JJL03-129	122	1380	200	20	3.10
JJL03-138	79	70	800	20	1.86
JJL03-139	83	1380	200	20	2.50
JJL03-143	0	40	365	20	0.602

Example 3: Effects of Sulfonation on Chromatographic Retention Behavior of the Sulfonated Resins

This example illustrates how the degree of sulfonation of the sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone) resins affected both the hydrophobic and ion-exchange behavior of the resins, as well as the retention properties of the resins.

The resins obtained from Example 2, JJL03-90, 100, 114, 119, 123, 124 and 143, were individually slurry-packed into 4.6 x 30 mm high performance liquid chromatography (HPLC) columns. The effect of sulfonation on hydrophobic retention and ion-exchange behavior was determined by examining retention of different neutral and basic analytes. The model compounds chosen were: acetaminophen, p-toluamide, caffeine, procainamide, ranitidine, amphetamine, methamphetamine, and m-toluidine. Structures of these model compounds are shown in Fig. 1. The mobile phase consisted of 40:60 methanol - 20 mM $(NH_4)H_2PO_4$, pH 3.0 with NH_4Cl as ionic stength modifier. Flow rate was 1.0 mL/min; temperature was 30°C. Injection volume was 5 μL. Each compound was individually injected. Detection was by UV at 254 nm.

In order to determine whether interactions were by hydrophobic or ionic mechanisms, the retention behavior was determined as a function of ionic strength. Figs. 2A and 2B show the effect of ionic strength on retention for unsulfonated poly(divinylbenzene-co-N-vinylpyrrolidone)(Oasis® HLB, Batch 6B), and for a relatively highly sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone)(Batch JJL03-100) (2.52 meq/g). As can be seen with the unsulfonated resin, there was a very slight increase in retention for all compounds as ionic

strength increased. This result is consistent with hydrophobic interaction mechanisms. Also, for the unsulfonated resin, there was only slight hydrophobic retention for the basic compounds under the conditions used, as the retention factor was ~<1. In the case of the sulfonated resin, little change in retention for neutral compounds was observed. However, retention of basic compounds was dramatically affected by ionic strength. Retention decreased significantly with increasing ionic strength, indicative of an ion-exchange mechanism.

Fig. 3 shows the effect of sulfonation of the resins on retention. 1M NH_4Cl was used to minimize the retention times. The graph shows that neutral compounds decreased in retention with increasing sulfonation. For the basic compounds, retention increased with increasing sulfonation up to ~ 1 meq/g. However, at higher levels of sulfonation, retention again decreased.

Example 4: Effects of Sulfonation on Solid Phase Extraction Performance of the Sulfonated Resins

This example illustrates the effect of sulfonation of the resins on solid phase extraction (SPE) performance of the sulfonated resins.

In order to evaluate SPE performance, an HPLC method was developed to examine recovery of several model compounds. A SymmetryShield™ RP8 column, 3.5 μm, 4.6 x 75 mm (Waters Corp., Milford, MA) was used, with a Sentry™ column (Waters Corp., Milford, MA) in-line. Flow rate was 2.0 mL/min; temperature was 36°C. Mobile phase consisted of 95:5 20 mM K_2HPO_4, pH 7.0 - methanol. Detection was by UV at 254 nm. Injection volume was 10 μL. A chromatogram

showing the optimized separation is shown in Fig. 4.

For the SPE evaluation, the following resins were used: Oasis® HLB Batch #6B, JJL03-143, JJL03-124 and JJL03-100. SPE was performed using 30 mg of each sorbent in a 96-well plate configuration. The procedure was as follows. The cartridge/well was conditioned with 1 mL methanol (~1 mL/min), and then equilibrated with 1 mL water. A 1 mL sample was loaded which consisted of either spiked phosphate buffered saline, or spiked porcine plasma. Samples were spiked to 10 μg/mL with acetaminophen, toluamide, caffeine and procainamide, and to 20 μg/mL with amphetamine, methamphetamine, and toluidine. The loaded samples were washed with 1 mL of 0.1 M HCl in water, then washed with 1 mL of methanol, and then eluted with 0.5 of 1 mL of methanol containing 2% NH_4OH. All fractions after the equilibration were collected. 50 μL of 10 μg/mL ranitidine were added to each sample. The samples were evaporated to dryness under an N_2 stream in a heating block. Samples were then reconstituted with 1 mL of 20 mM phosphate buffer, pH 7.0.

Initial SPE performance experiments were done in phosphate-buffered saline. A complete mass balance was performed on SPE fractions using sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone), Batch #JJL03-143. Table 2 shows recovery and mass balance results.

Table 2 - Recovery and Mass Balance for SPE of Model Compounds from Spiked Phosphate Buffered Saline Using JJL03-143

JJL03-143	Load		Wash (HCl)		Wash (MeOH)		Elute (NH_4OH, MeOH)		Elute2 (NH_4OH, MeOH)		Mass bal.
Compound	Ave	st.dev	Ave	st. dev	Ave	st. dev	Ave	st. dev	Ave	st. dev	Ave
Acetaminophen	0.000	0.000	0.000	0.000	0.994	0.013	0.012	0.001	0.000	0.000	1.007
Caffeine	0.000	0.000	0.000	0.000	0.960	0.013	0.048	0.010	0.000	0.000	1.008
Toluamide	0.000	0.000	0.000	0.000	0.974	0.010	0.000	0.000	0.000	0.000	0.974
Procainamide	0.000	0.000	0.000	0.000	0.000	0.000	0.992	0.010	0.000	0.000	0.992
Amphetamine	0.000	0.000	0.000	0.000	0.000	0.000	0.474	0.100	0.000	0.000	0.474
Methamphetamine	0.000	0.000	0.000	0.000	0.000	0.000	0.428	0.108	0.000	0.000	0.428
Toluidine	0.000	0.000	0.000	0.000	0.000	0.000	0.109	0.189	0.000	0.000	0.109

Note that amphetamine, methamphetamine and toluidine were not fully recovered in all cases. This was attributed to losses during evaporation, as these compounds are semi-volatile. In experiments where samples were not dried down, complete recovery was obtained. Results from the saline recovery study showed that breakthrough did not occur in the load or HCl wash steps in any case. All compounds eluted in the methanol wash for Oasis® HLB, while only neutral compounds eluted for all the sulfonated resins. Basic compounds could be completely eluted with the methanol/NH_4OH solution. For the sulfonated resin, most of the caffeine eluted in the first methanol wash. In addition, recovery in each fraction was found to depend on the degree of sulfonation; the least sulfonated resins gave greatest recovery in the first methanol wash. This unusual result is attributed to caffeine being a weak base, with a pK_b of 13.9. Another observation was that acetaminophen had a slight amount of breakthrough (~1%) in the methanol/base elution for the sulfonated resins.

Similar results were obtained when using plasma. Table 3 shows results from recoveries obtained on three different sorbents: Oasis® HLB Batch 6B, JJL03-100 and JJL03-124.

Table 3 - Recovery Results from SPE of Spiked Porcine Plasma (n=3)

HLB #6B (0.00 meq/g)	Wash (MeOH)		Elute (MeOH, NH_4OH)		Mass balance
	Ave.	st. dev.	Ave.	st. dev.	
Acetaminophen	1.009	0.021	0.000	0.000	1.009
Caffeine	0.997	0.025	0.000	0.000	0.997
Toluamide	0.995	0.038	0.000	0.000	0.995
Procainamide	0.239	0.002	0.038	0.005	0.277
Amphetamine	0.825	0.103	0.000	0.000	0.825
Methamphetamine	1.230	0.044	0.000	0.000	1.230
Toluidine	0.569	0.037	0.000	0.000	0.569

JJL03-100 (2.52 meq/g)	Wash (MeOH)		Elute (MeOH, NH_4OH)		Mass balance
	Ave.	st. dev.	Ave.	st. dev.	
Acetaminophen	0.299	0.026	0.018	0.001	0.317
Caffeine	0.077	0.009	0.090	0.004	0.167
Toluamide	0.823	0.011	0.053	0.007	0.876
Procainamide	0.000	0.000	0.842	0.031	0.842
Amphetamine	0.000	0.000	0.708	0.084	0.706
Methamphetamine	0.000	0.000	0.732	0.180	0.732
Toluidine	0.000	0.000	0.479	0.059	0.479

Table 3 - Recovery Results from SPE of Spiked Porcine Plasma (n=3) (Cont=d.)

JJL03-124 (0.90 meq/g)	Wash (MeOH)		Elute (MeOH, NH_4OH)		Mass balance
	Ave.	st. dev.	Ave.	st. dev.	
Acetaminophen	0.078	0.003	0.017	0.004	0.995
Caffeine	0.901	0.058	0.083	0.054	0.984
Toluamide	0.347	0.012	0.020	0.001	0.967
Procainamide	0.000	0.000	0.873	0.003	0.873
Amphetamine	0.000	0.000	0.871	0.020	0.871
Methamphetamine	0.000	0.000	0.969	0.023	0.969
Toluidine	0.000	0.000	0.323	0.091	0.393

Neutrals eluted in the methanol wash; bases eluted in the methanol/ammonium hydroxide step. HPLC analysis of unspiked plasma extracts from the sulfonated resins are shown in Figs. 5A and 5B, where ranitidine is an internal standard.

Protein in the extracts was quantitated by Coomassie blue. Two different lots of plasma were tested. Results are shown in Table 4.

Table 4 - Results from Protein Assay of Methanol/NH_4OH Extracts as Determined by Coomassie Blue

	MeOH/NH4OH Elution Protein Concentration (mg/mL)	
Sorbent	Plasma Lot #171	Plasma Lot #180
Oasis® HLB	0.012	0.012
JJL03-124	0.014	0.010
JJL03-100	0.006	0.006

Protein in the basified methanol was found to be comparable for Oasis® HLB, JJL03-100 and JJL03-124. As a comparison, these protein amounts were about 5-fold less than what is typically observed using the recommended SPE protocol ("Water Oasis® HLB Extraction Cartridges and Plates," ©1997 Waters Corp., 6/97 WB025-US) for Oasis® HLB cartridges (from the methanol elution step).

At high sulfonation loadings, the plasma load passing through the resin became turbid. A related observation was that the flow rate was found to decrease at high sulfonation loadings. These observations are attributed to the acidity of the resin. The most sulfonated resins have the highest acidity. Thus, passing plasma through the resin was similar to performing an acid precipitation, which makes the sample more turbid, and also can plug up the frit and the packed bed containing the resin.

Example 5: <u>Chloromethylation of poly(divinylbenzene-co-N-vinylpyrrolidone) porous resins.</u>

Poly(divinylbenzene-co-N-vinylpyrrolidone), OASIS® HLB, obtained from Waters Corp., Milford, MA, was derivatized with hydrochloric acid (12 Molar, 36.5-38%, A.C.S. reagent, J.T. Baker, 9535-03, Phillipsburgh, NJ) and paraformaldehyde (95%, Aldrich Chemical, 15,812-7, Milwaukee, WI). A 3 L, three-necked, round-bottom flask was fitted with a thermometer, agitator, condenser and reactor temperature control system. Hydrochloric acid was introduced into the flask (see Table 5 for the amount of hydrochloric acid). Then, the agitation and the temperature control were started. The agitator was a ground-glass shaft fitted through the proper Teflon bearing into the center opening atop the flask. The Teflon paddle was single-bladed. The agitation rate was adjusted to ensure

adequate mixing. The poly(divinylbenzene-co-N-vinylpyrrolidone), OASIS® HLB, was charged (see Table 5 for the amount of OASIS® HLB). Next, the paraformaldehyde was charged (see Table 5 for the amount of paraformaldehyde). The reaction mixture was stirred for a certain period of time at constant temperature (see Table 5 for reaction time and temperature). The reaction mixture was cooled, and the acid solution was filtered. The chloromethylated poly(divinylbenzene-co-N-vinylpyrrolidone) copolymer was collected and washed with water until the pH of the slurry was ≥ 5.0. The filter cake of chloromethylated poly(divinylbenzene-co-N-vinylpyrrolidone) copolymer was then washed twice with methanol (HPLC grade, J.T. Baker, 9535-03, Phillipsburgh, NJ) and dried in vacuo for 15 hours at 80°C. The level of chloromethylation was determined by chlorine elemental analysis (Atlantic Microlab Inc., Norcross, GA). The loading of chloromethyl groups (CH_2Cl) on the copolymer is listed in Table 5.

Reaction time, reaction temperature, and the hydrochloric acid molarity were all found to influence the loading of chloromethyl groups on the poly(divinylbenzene-co-N-vinylpyrrolidone) copolymer. Different combinations of these three variables and the resultant chloromethyl loadings are listed in Table 5.

Table 5 -Chloromethylated Poly(divinylbenzene-co-N-vinylpyrrolidone) Porous Resins and Respective Reaction Conditions

Batch No.	Temperature (°C)	Reaction Time (h)	HCl Molarity	Oasis® HLB (gram)	HCl (gram)	Paraform-aldehyde (gram)	Chloromethyl Loading (meq/g)
ARP03-132	50	1	11.1	30	450	17	0.61
ARP02-159	60	16	7.5	25	385	14.5	0.72
ARP02-98	40	2	12.0	16	225	17	0.73
ARP03-132	50	2	11.1	30	450	17	0.74
ARP02-92	50	2	12.0	16	225	15	0.83
ARP03-132	50	6	11.1	30	450	17	0.89
ARP03-132	50	16	11.1	30	450	17	1.00
ARP02-161	60	16	9.0	25	385	14.5	1.01
ARP03-133	70	2	11.1	30	450	17	1.03
ARP02-56	60	5	12.0	16	250	8	1.14
ARP02-163	60	16	10.5	25	385	14.5	1.15
ARP03-133	70	16	11.1	30	450	17	1.23
ARP03-133	70	6	11.1	30	450	17	1.24
ARP02-57	60	25	12.0	16	250	8	1.35
JJL03-170	65	21	12.0	5	150	8	1.38
JJL03-182	70	25	12.0	61	926	51	1.43

Example 6. Amination of chloromethylated poly(divinylbenzene-co-N-vinylpyrrolidone) porous resins.

Chloromethylated poly(divinylbenzene-co-N-vinylpyrrolidone) porous resins, prepared as described in Example 5, were reacted with the following tertiary amines (all purchased from Aldrich Chemical, Milwaukee, WI): Trimethylamine (TMA, 40 wt.% solution in water, 43,326-8), triethylamine (TEA, 99%, 13,206-3), *N,N*-dimethylethylamine (DMEA, 99%, 23,935-6), *N,N*-diethylmethylamine (DEMA, 98%, D9,820-3), *N,N*-dimethylbutylamine (DMBA, 99%, 36,952-7), and N-methylpyrrolidine (NMP, 97%, M7,920-4). A general amination procedure is provided below. The chloromethylation load and the steric size of the reacting amine alkyl groups (see Hirsch, J.A. in *Topics in Stereochemistry, Volume 1*, Allinger, N.L.; Eliel, E.D., Eds. Wiley: New York, 1967, Chapter 1) were found to generally influence the loading of ammonium groups on the poly(divinylbenzene-co-N-vinylpyrrolidone) copolymer. A general reaction procedure is given below. Different combinations of step 1 chloromethyl loading, amine type, and reaction temperature, and the resultant quarternary amine loadings are listed in Table 6.

A 250 mL, three-necked, round-bottom flask was fitted with a thermometer, agitator, condenser and reactor temperature control system. Trialkylamine was introduced into the flask (see Table 6 for the amount of the respective amine), and the agitation and the temperature control were started. The agitator was a ground-glass shaft fitted through the proper Teflon bearing into the center opening atop the flask. The Teflon paddle was single-bladed. The chloromethylated poly(divinylbenzene-co-N-vinylpyrrolidone) was charged (see

Table 6 for the amount of resin), and the agitation rate was adjusted to ensure adequate mixing. The reaction mixture was stirred for a certain period of time at constant temperature (see Table 6 for reaction time and temperature). The reaction mixture was cooled, and the amine was filtered. The aminated poly(divinylbenzene-co-N-vinylpyrrolidone) copolymer was collected and washed with water until the pH of the slurry was ≤ 5.5. The filter cake of aminated poly(divinylbenzene-co-N-vinylpyrrolidone) copolymer was then washed twice with methanol (HPLC grade, J.T. Baker, 9535-03, Phillipsburgh, NJ) and dried in vacuo for 15 hours at 80°C. The level of amination was determined by titration. The amount of methylenetrialkylammonium groups ($CH_2NR_3^+$ Cl^-) on the copolymer is listed in Table 6.

Table 6 - Aminated Poly(divinylbenzene-co-N-vinylpyrrolidone) Porous Resins and Respective Reaction Conditions

Batch No.	Temperature (°C)	Reaction Time (h)	Chloro-methyl resin (gram)	Chloro-methyl load (meq/g)	Amine Type	Amine Amount (gram)	Tetraalkylammonium Group Loading (meq/g)
ARP-2-153	88	24	50	0.76	TEA	750	0.012
ARP-3-125	50	3.0	12	0.74	DMBA	50	0.030
ARP-2-145	85	25	50	1.19	TEA	750	0.041
JEO-6-65	40	4.0	11	1.01	DMBA	50	0.054
ARP-2-108	50	25	97	1.38	TEA	388	0.067
ARP-2-136	40	25	100	0.76	TMA	1000	0.090
JEO-6-48	37	19	9	1.11	DMEA	47	0.109
JEO-6-47	64	17	9	1.11	DEMA	47	0.114
ARP-3-113	50	4.0	5	1.03	DMBA	50	0.157
ARP-3-139	65	4.0	11	1.23	DMBA	50	0.165
JEO-6-43	81	16	8	1.11	NMP	54	0.173
ARP-2-147	50	5	50	1.19	TMA	500	0.184
JEO-6-64	85	4.0	11	1.23	DMBA	50	0.216
ARP-2-115	50	25	5	1.42	TMA	50	0.260
ARP-2-121	50	25	5	1.07	TMA	50	0.290
ARP-3-110	93	5.0	6	1.36	DMBA	50	0.320

In conclusion, the experiments demonstrated that sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone) can be used with a generic procedure for SPE of basic compounds. In addition, it can be used as a tool to perform class fractionation of neutral and basic compounds.

Those skilled in the art will be able to ascertain using no more than routine experimentation, many equivalents of the specific embodiments of the invention described herein. These and all other equivalents are intended to be encompassed by the following claims.

What is claimed is:

CLAIMS

1. A compound of the formula:

$$-\!\left(A\right)_n\!-\!\left(B\right)_m\!-\!\left(C\right)_p\!- \qquad \text{(I)}$$

and salts thereof,

wherein the order of A, B and C may be random, block, or a combination of random and block;

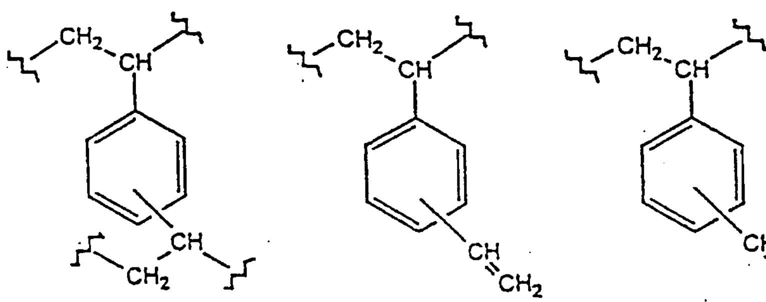
wherein

$$\frac{1}{100} < \frac{(p+n)}{m} < \frac{100}{1}$$

and

$$\frac{1}{500} < \frac{p}{n} < \frac{100}{1}$$

wherein A is selected from the group consisting of



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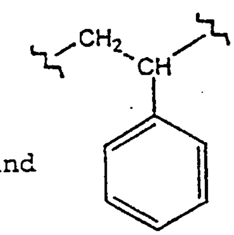
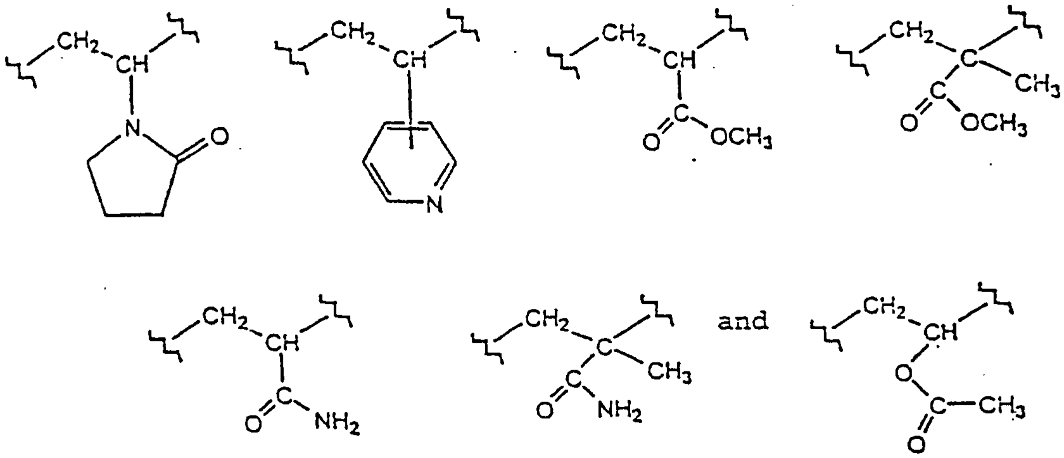
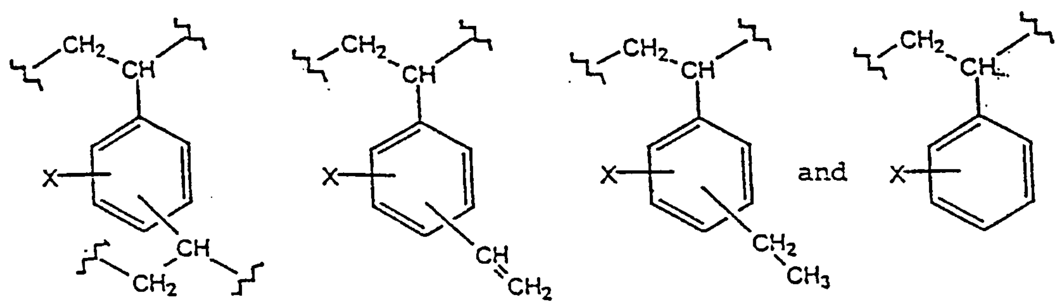


wherein B is selected from the group consisting of



wherein C is A or modified A, wherein modified A is selected from the group consisting of



and

wherein X is selected from the group consisting of SO_3H, CH_2CO_2H, $CH_2CH(CO_2H)_2$, CO_2H, PO_3H_2, PO_2H_2, $CH_2PO_3H_2$, CH_2Cl, CH_2NH_2, $CH_2N[(CH_2)_yCH_3]_2$ wherein y is any integer from 0 to 18, $CH_2N^+[(CH_2)_{y=}CH_3]_3D^-$ wherein y= is any integer from 0 to 18 and D^- is an anion, SO_2NHR wherein R is polyethylenimine, and CH_2NHR wherein R is polyethylenimine.

2. The compound according to claim 1 wherein X is present at a concentration of about 0.1 to about 5.0 milliequivalents per gram of compound.

3. The compound according to claim 1 wherein X is present at a concentration of about 0.6 to about 3.2 milliequivalents per gram of compound.

4. The compound according to claim 1 wherein X is present at a concentration of about 0.8 to about 2.1 milliequivalents per gram of compound.

5. The compound according to claim 1 wherein X is present at a concentration of about 1.0 milliequivalents per gram of compound.

6. The compound according to claim 1 wherein X is selected from the group consisting of SO_3H, $CH_2PO_3H_2$, and CH_2CO_2H.

7. The compound according to claim 6 wherein X is SO_3H.

8. A porous resin for solid phase extraction or chromatography formed by copolymerizing at least one hydrophobic monomer and at least one hydrophilic monomer so as to form a copolymer and subjecting said copolymer to a sulfonation reaction so as to form a sulfonated copolymer comprising at least one ion-exchange functional group, at least one hydrophilic component and at least one hydrophobic component.

9. The porous resin of claim 8 wherein said hydrophobic monomer is divinylbenzene.

10. The porous resin of claim 8 wherein said hydrophilic monomer is N-vinylpyrrolidone.

11. The porous resin of claim 8 wherein said copolymer is a poly(divinylbenzene-co-N-vinylpyrrolidone).

12. The porous resin of claim 8 wherein said porous resin is a sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone).

13. The porous resin of claim 12 wherein said sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone) has sulfonate groups present at a concentration of about 0.1 to about 5.0 milliequivalents per gram of porous resin.

14. A porous resin for solid phase extraction or chromatography comprising at least one ion-exchange functional group, at least one hydrophilic component and at least one hydrophobic component.

15. A method for treating a solution to isolate or remove a solute, comprising:

contacting a solution having a solute with a porous resin under conditions so as to allow sorption of said solute to said porous resin;

said porous resin comprising at least one ion-exchange functional group, at least one hydrophilic polar component and at least one hydrophobic component.

16. The method of claim 14 wherein said ion-exchange functional group is selected from the group consisting of SO_3H, CH_2CO_2H, $CH_2CH(CO_2H)_2$, CO_2H, PO_3H_2, PO_2H_2, $CH_2PO_3H_2$, CH_2Cl, CH_2NH_2, $CH_2N[(CH_2)_yCH_3]_2$ wherein y is any integer from 0 to 18, $CH_2N^+[(CH_2)_{y=}CH_3]_3D^-$ wherein y= is any integer from 0 to 18 and D^- is an anion, SO_2NHR wherein R is polyethylenimine, and CH_2NHR wherein R is polyethylenimine.

17. The method of claim 16 wherein said ion-exchange functional group is selected from the group consisting of SO_3H, $CH_2PO_3H_2$, and CH_2CO_2H.

18. The method of claim 17 wherein said ion-exchange functional group is SO_3H.

19. The method of claim 15 wherein said ion-exchange functional group is present at a concentration of about 0.1 to about 5.0 milliequivalents per gram of porous resin.

20. The method of claim 15 wherein said hydrophilic polar component is selected from the group consisting of an amide group, ester group, carbonate group, carbamate group, urea group, hydroxy group and pyridyl group.

21. The method of claim 15 wherein said porous resin comprises a copolymer having at least one ion-exchange functional group, said copolymer comprising at least one hydrophilic monomer and at least one hydrophobic monomer.

22. The method of claim 21 wherein said hydrophilic monomer comprises a heterocyclic group.

23. The method of claim 22 wherein said heterocyclic group is a pyridyl group or a pyrrolidonyl group.

24. The method of claim 23 wherein said pyridyl group is selected from the group consisting of 2-vinylpyridine, 3-vinylpyridine and 4-vinylpyridine.

25. The method of claim 23 wherein said pyrrolidonyl group is N-vinylpyrrolidone.

26. The method of claim 21 wherein said hydrophobic monomer comprises a group selected from the group consisting of a phenyl group, a phenylene group, a straight chain C_2-C_{18}-alkyl group and a branched chain C_2-C_{18}-alkyl group.

27. The method of claim 26 wherein said hydrophobic monomer is styrene or divinylbenzene.

28. The method of claim 26 wherein said hydrophobic monomer is divinylbenzene.

29. The method of claim 21 wherein said copolymer is a poly(divinylbenzene-co-N-vinylpyrrolidone).

30. The method of claim 15 wherein said porous resin is a compound of formula I and salts thereof.

31. The method of claim 15 wherein said porous resin is a sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone).

32. The method of claim 31 wherein said sulfonate group is present at a concentration of about 0.1 to about 5.0 millequivalents per gram of porous resin.

33. The method of claim 31 wherein said porous resin comprises at least about 12 mole percent N-vinylpyrrolidone.

34. The method of claim 31 wherein said porous resin comprises less than about 30 mole percent N-vinylpyrrolidone.

35. The method of claim 15 wherein said porous resin is in the form of a bead.

36. The method of claim 35 wherein said bead has an average size of about 3 to about 500 micrometers.

37. The method of claim 15 wherein said porous resin is incorporated in a matrix.

38. The method of claim 15 wherein said porous resin has solid phase extraction capability.

39. The method of claim 15 wherein said solute is selected from the group consisting of a drug, pesticide, herbicide, biomolecule, toxin, pollutant, metabolite, and a degradation product thereof.

40. The method of claim 15 wherein said solution is selected from the group consisting of water, an aqueous solution, and a mixture of water or an aqueous solution and a water-miscible polar organic solvent.

41. The method of claim 15 wherein said solution is selected from the group consisting of blood, plasma, urine, cerebrospinal fluid, synovial fluid, a tissue extract, groundwater, surface water, drinking water, a soil extract, a food substance, an extract of a food substance, and natural products extractions from plants and broths.

42. The method of claim 15 wherein said porous resin is within an open-ended container.

43. The method of claim 15 further comprising the step of removing said solute from said porous resin.

44. A method for analytically determining the level of a solute in a solution, comprising:

contacting a solution having a solute with a porous resin under conditions so as to allow sorption of said solute to said porous resin;

said resin comprising at least one ion-exchange functional group, at least one hydrophilic polar component and at least one hydrophobic component;

washing said porous resin having said sorbed solute with a solvent under conditions so as to desorb said solute from said porous resin; and

analytically determining the level of said desorbed solute present in said solvent after said washing.

45. The method of claim 44 wherein said porous resin is a compound of formula I and salts thereof.

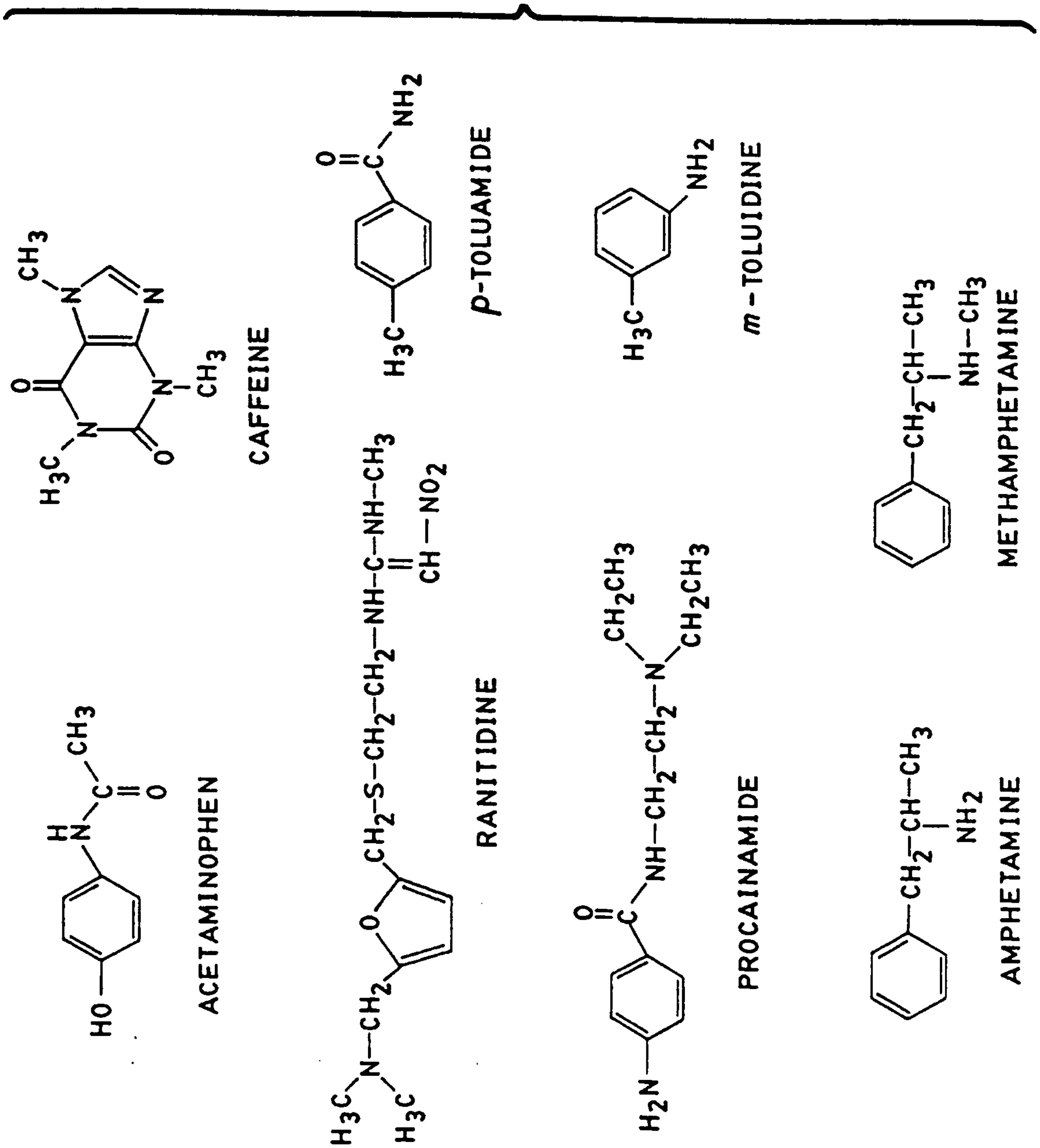
46. The method of claim 45 wherein said porous resin is a sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone).

47. A solid phase extraction cartridge comprising a porous resin packed inside an open-ended container, said porous resin comprising at least one ion-exchange functional group, at least one hydrophilic polar component and at least one hydrophobic component.

48. The solid phase extraction cartridge of claim 47 wherein said porous resin is a compound of formula I and salts thereof.

49. The solid phase extraction cartridge of claim 48 wherein said porous resin is a sulfonated poly(divinylbenzene-co-N-vinylpyrrolidone).

FIG.1


ACETAMINOPHEN
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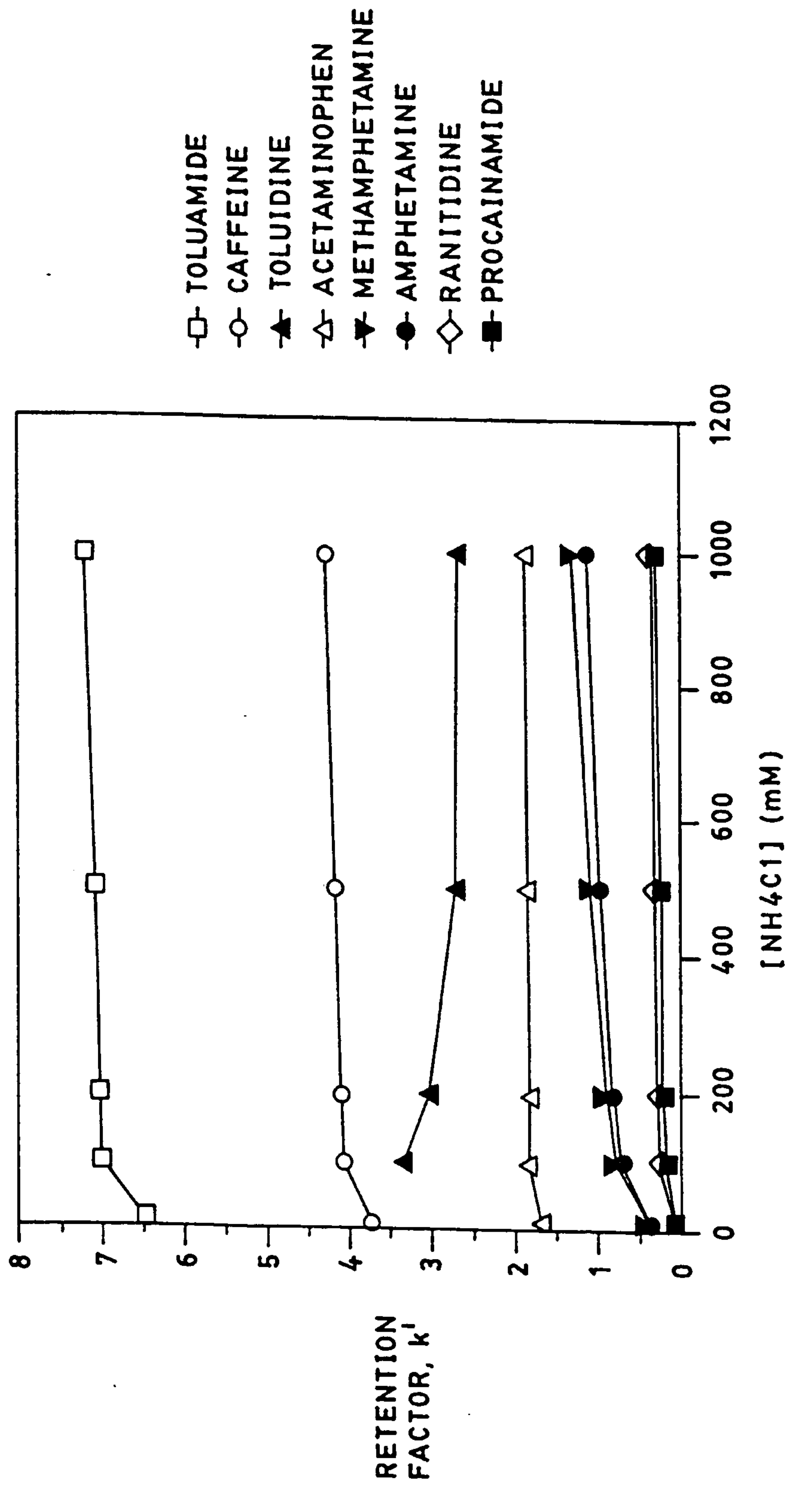
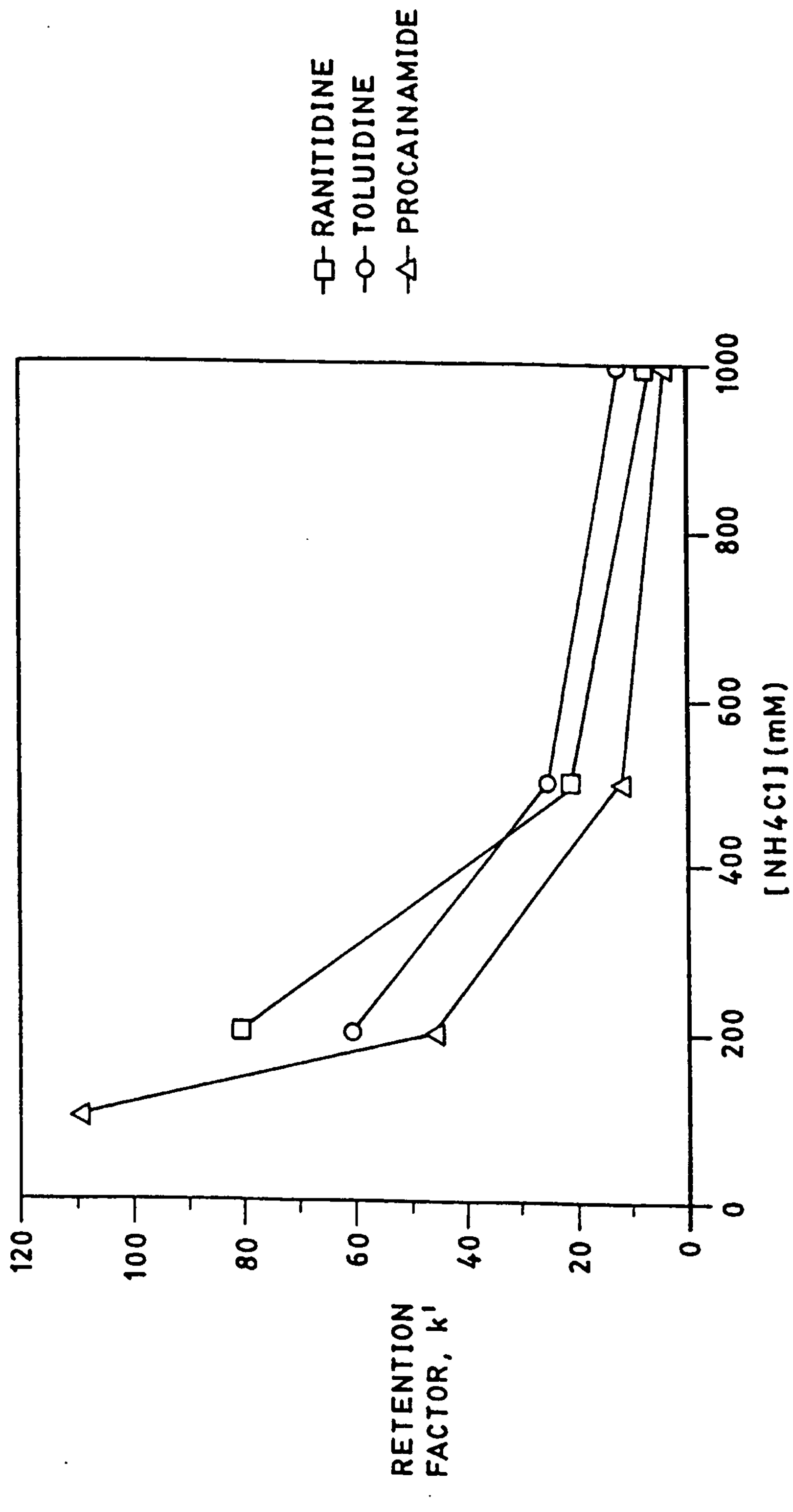
RANITIDINE
p-TOLUAMIDE
PROCAINAMIDE
m-TOLUIDINE
AMPHETAMINE
METHAMPHETAMINE



TOLUAMIDE
CAFFEINE
TOLUIDINE
ACETAMINOPHEN
METHAMPHETAMINE
AMPHETAMINE
RANITIDINE
PROCAINAMIDE
RETENTION FACTOR, k'
0
1
2
3
4
5
6
7
8
0
200
400
600
800
1000
1200
[NH4C1] (mM)

FIG. 2A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TOLUIDINE
PROCAINAMIDE
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60
80
100
120
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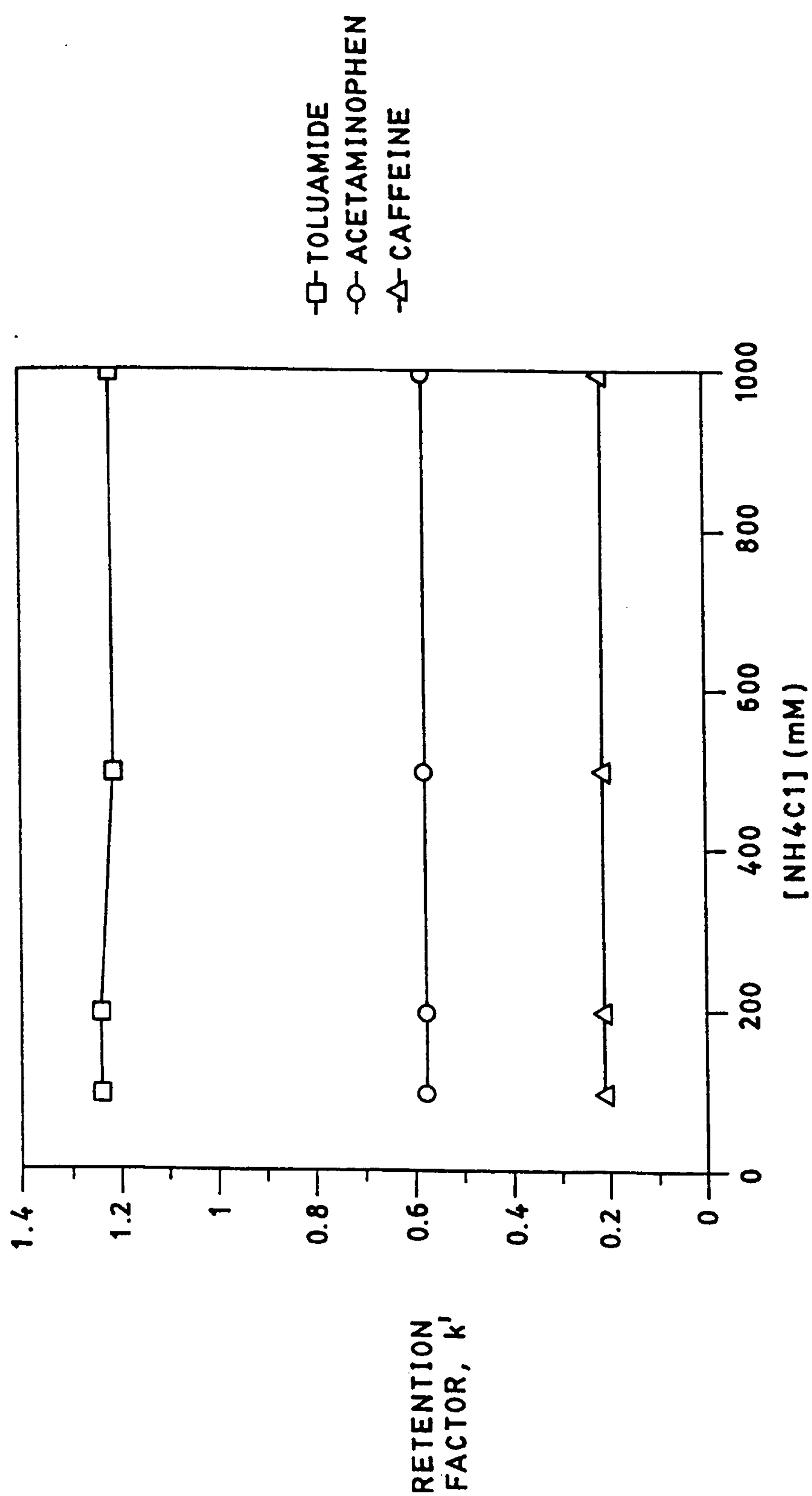
600
800
1000
[NH4Cl] (mM)

FIG. 2B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ACETAMINOPHEN
CAFFEINE
RETENTION FACTOR, k'
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1.2
1
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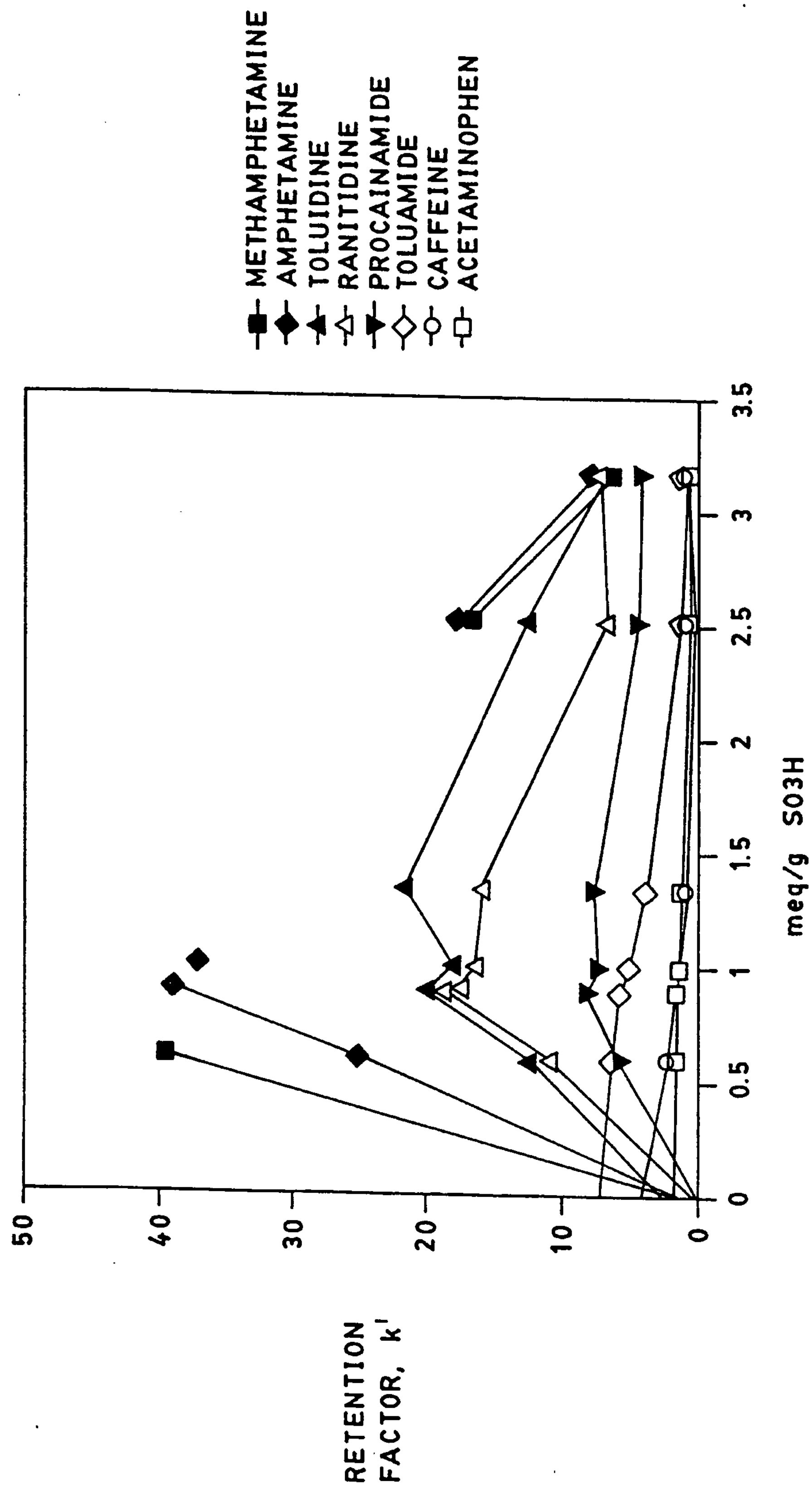
0.6
0.4
0.2
0
200
400
600
800
1000
[NH4Cl] (mM)

FIG. 2C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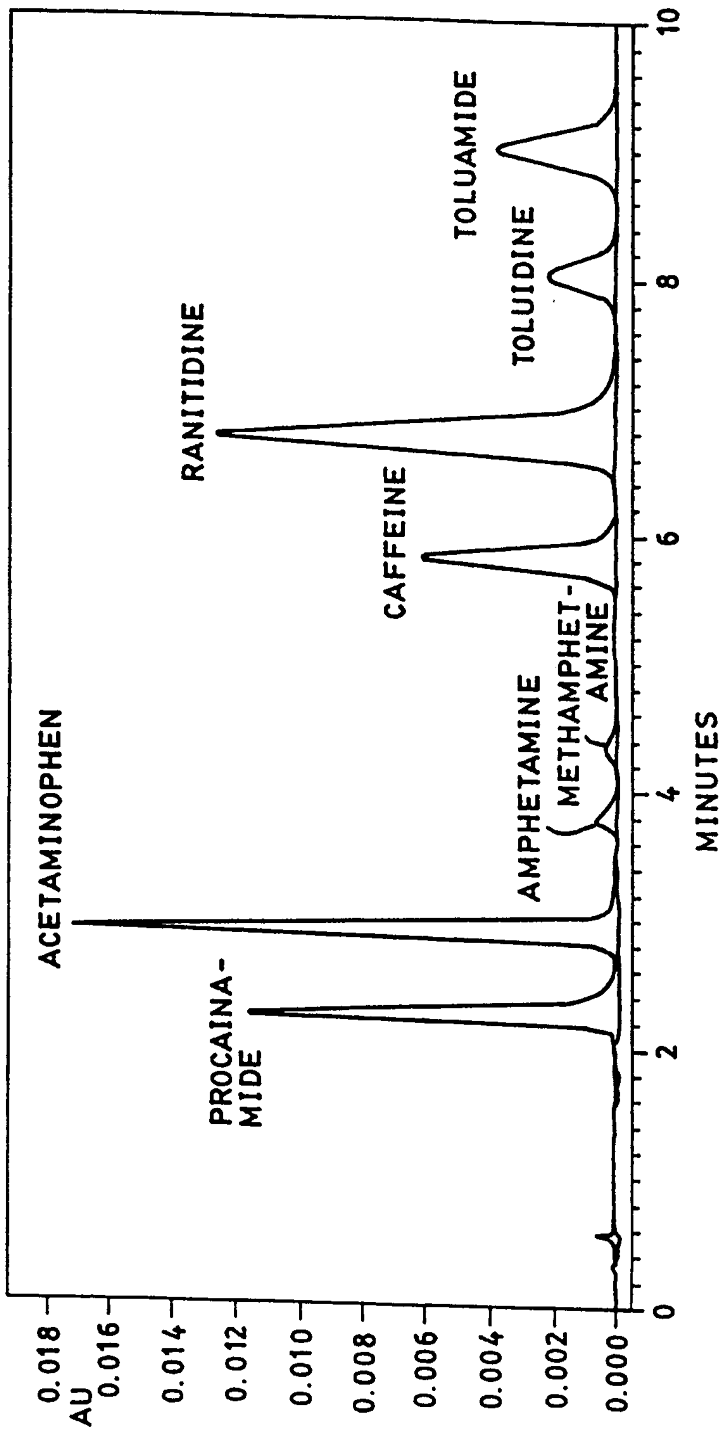
AMPHETAMINE
TOLUIDINE
RANITIDINE
PROCAINAMIDE
TOLUAMIDE
CAFFEINE
ACETAMINOPHEN
RETENTION FACTOR, k'
0
10
20
30
40
50
0
0.5
1
1.5
2
2.5
3
3.5
meq/g SO3H

FIG. 3


AU
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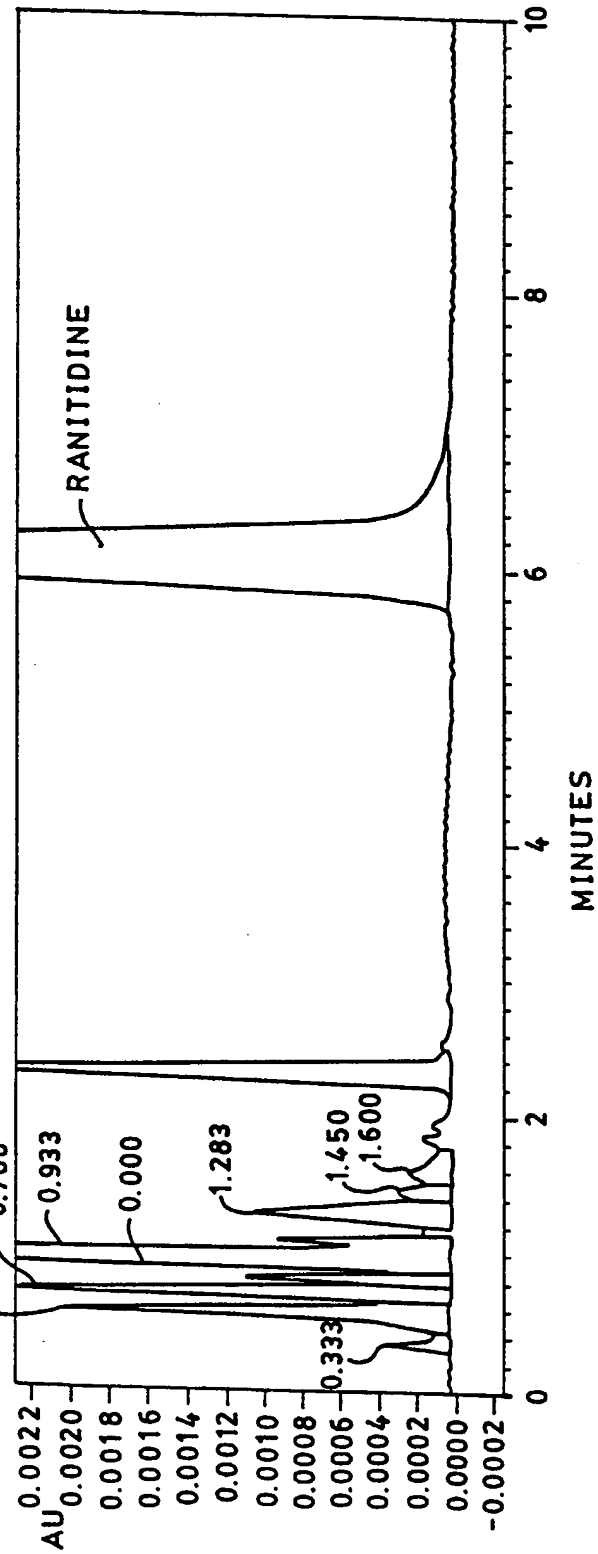
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
0
2
4
6
8
10
MINUTES
PROCAINA-
MIDE
ACETAMINOPHEN
AMPHETAMINE
METHAMPHET-
AMINE
CAFFEINE
RANITIDINE
TOLUIDINE
TOLUAMIDE

FIG. 4


RANITIDINE
0.567
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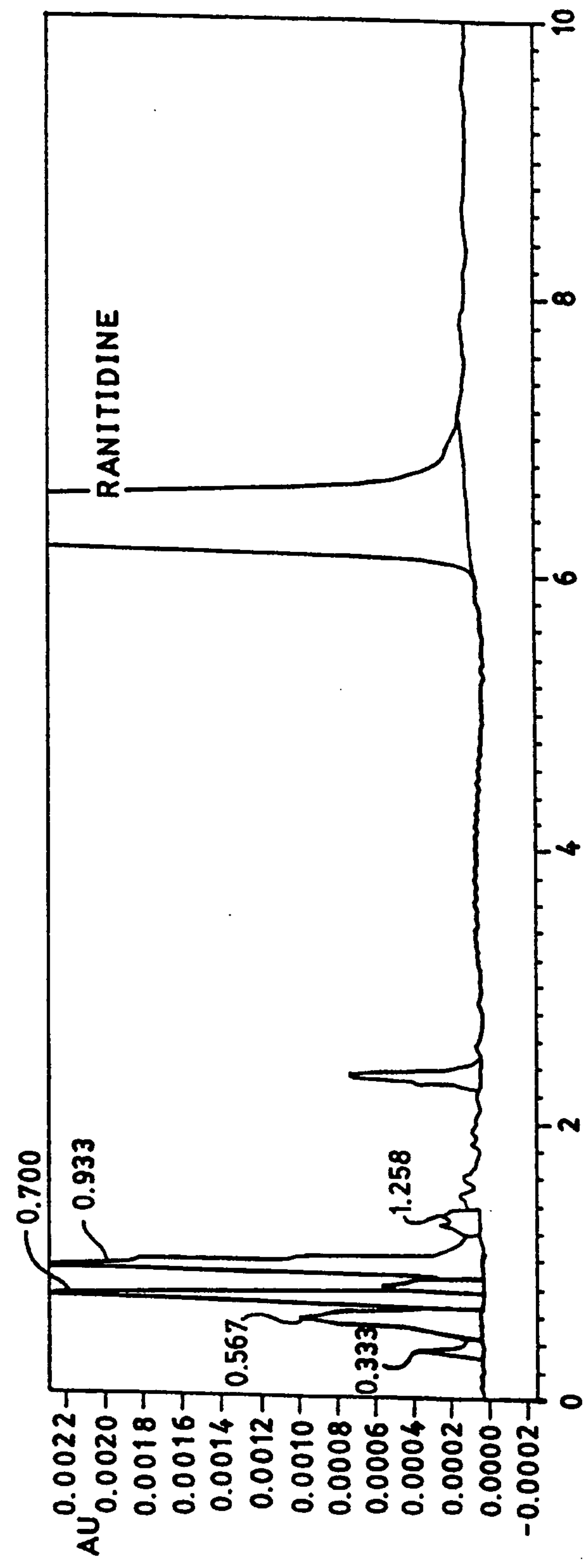
0.933
0.000
1.283
1.450
1.600
0.333
AU
0.0022
0.0020
0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
-0.0002
0
2
4
6
8
10
MINUTES

FIG. 5A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0.333
AU
0.0022
0.0020
0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
-0.0002
0
2
4
6
8
10
MINUTES

FIG. 5B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/13241

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :C08F 8/12, 8/30, 8/36; C08J 9/00
US CL :521/31, 32, 33; 525/326.9
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 521/31, 32, 33; 525/326.9

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3,985,540 A (FEIN et al) 12 October 1976, see columns 2 and 3.	1-49
X	US 3,954,682 A (FEIN et al) 04 May 1976, see entire document.	1-49
A	US 3,946,749 A (PAPANTONIOU) 30 March 1976.	1-49

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search

30 AUGUST 1999

Date of mailing of the international search report

13 SEP 1999

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